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Core-to-Core Collaborative Research between Earthquake Research Institute, University of Tokyo and Disaster Prevention Research Institute, Kyoto University during FY2014 to FY2018

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1 The research program titled “Earthquake and
2 Volcano Hazards Observation and Research
3 Program” was started in fiscal year (FY) 2014 as a
4 new five-year project authorized and funded by the
5 Council for Science and Technology of the Ministry
6 of Education, Culture, Sports, Science and
7 Technology. It included a new format of
8 collaborative research called, “Core-to-Core
9 Collaborative Research between Earthquake
10 Research Institute, University of Tokyo and
11 Disaster Prevention Research Institute, Kyoto
12 University”. In this format, two types of research,
13 “Participation Type Research” and “Subject
14 Proposal Type Research” were conducted from
15 FY2015. A preliminary study was performed in
16 FY2015 for “Integrated Research” of
17 “Participation Type Research,” which developed a
18 framework for seismic risk evaluation at
19 prefectural offices of Osaka and Kochi for an
20 earthquake occurring along the Nankai Trough,
21 considering the epistemic uncertainty. The
22 secondary study was performed from FY2016
23 through to FY2018, wherein the methodology for
24 the seismic risk evaluation was improved on three
25 aspects: i.e., revision in ground motion prediction
26 models considering the saturation effect, revision in
27 loss models in terms of the fatalities as well as the
28 direct losses of buildings, and extension of target
29 sites to the whole of Osaka and Kochi prefectures.
30 The results suggest that the epistemic uncertainty
31 in the ground motion prediction models is most
32 sensitive to the overall uncertainty of seismic risk.
33 Along with “Integrated Research”, a total of 14
34 “Research on Specific Topics” related to time-
35 dependent risk analysis, economical risk evaluation,
36 source characterization, structural damage
37 estimation models, ground motion estimation
38 models, soil amplification models and disaster
39 prevention planning considering the uncertainty of
40 risk assessment, were studied during this period in

41 order to improve the risk assessment studies for
42 “Integrated Research”. With respect to “Subject
43 Proposal Type Research,” a total of 27 individual
44 research themes focused on research to understand
45 hazards/risks by earthquakes and volcanic
46 eruptions and to mitigate disasters by them.

47 **Keywords:** core-to-core collaborative research,
48 disaster mitigation, earthquakes, volcanoes, hazard
49 estimation, risk evaluation, Nankai Trough earthquake

50 1. Introduction

51 The research program “Observation and Research
52 Program for Prediction of Earthquakes and Volcanic
53 Eruptions”, authorized and funded by the Council for
54 Science and Technology of the Ministry of Education,
55 Culture, Sports, Science and Technology (MEXT),
56 was planned for FY2009 through to FY2013. It faced
57 criticism after the 2011 off the Pacific coast of Tohoku
58 Earthquake, as the outputs from the program were not
59 effective in mitigating the disaster caused by the
60 earthquake. At the end of this five-year program in
61 FY2013, a new five-year research program was
62 proposed that placed emphasis on the mitigation of
63 disasters by earthquakes and volcanic eruptions in
64 addition to conducting observation and research for
65 understanding earthquakes and volcanic eruptions. In
66 FY2014, a new five-year research program called
67 “Earthquake and Volcano Hazards Observation and
68 Research Program” was initiated, which included a
69 new format of collaborative research called, “Core-to-
70 Core Collaborative Research between Earthquake
71 Research Institute, University of Tokyo (ERI) and
72 Disaster Prevention Research Institute, Kyoto
73 University (DPRI)” (Core-to-Core Research). It was
74 clarified that the aim of the research program is not
75 only for observation and research for earthquake and
76 volcanic eruption prediction, but for conducting
77 researches that are aimed at contributing to estimating

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1 and mitigating disasters caused by earthquakes and
2 volcanic eruptions. ERI is the “Joint Usage/Research
3 Center for Earthquake and Volcano Sciences” and
4 DPRI is the “Joint Usage/Collaborative Research
5 Center for Multi-disciplinary Disaster Prevention
6 Study.” The collaborative research between these two
7 institutes (research centers) is expected to accelerate
8 researches mitigating disaster caused by earthquakes
9 and volcanic eruptions.

10 In this new format of collaborative research, two
11 types of researches were conducted, namely
12 “Participation Type Research” and “Subject Proposal
13 Type Research”. Groups of or individual researchers
14 proposed ideas related to understanding the occurrence
15 of disaster by earthquakes or volcanic eruptions and
16 their consequence, as well as how to mitigate the
17 damage for both research types. For “Participation
18 Type Research”, groups consisting of researchers from
19 many institutions in Japan including ERI and DPRI,
20 proposed research related to probabilistic seismic risk
21 assessment associated with the occurrence of an
22 earthquake along the Nankai Trough. “Subject
23 Proposal Type Research” aimed to promote disaster
24 mitigation research in a wider range of research areas.
25 The proposals for both research types were evaluated
26 by the “Coordinating Committee for Core-to-Core
27 Research”.

28 This article will outline the Core-to-Core Research
29 from FY2014 and FY2018.

30 2. Structure of the Research Types

31 2.1. Participation Type Research

32 In “Participation Type Research”, research related
33 to probabilistic seismic risk assessment at Osaka and
34 Kochi prefectures associated with the occurrence of an
35 earthquake along the Nankai Trough was conducted.

36 This research had two objectives: conduct
37 integrated research aimed at “Construction of a New
38 Paradigm for Improving Uncertainty of Risk
39 Evaluation for Large Magnitude Earthquakes” that
40 combines research areas from source process to
41 stakeholder involvement; and study specific research
42 topics that were considered necessary to improve and
43 update “Integrated Research.”

44 2.1.1. Integrated Research

45 “Integrated Research” was formulated with 7
46 research subgroups related to seismic risk evaluation,
47 i.e. source process, wave propagation and deep
48 subsurface structure, strong motion estimation,
49 shallow subsurface structure, structural damage
50 estimation, risk evaluation, and stakeholder
51 involvement. Another subgroup was formed to
52 develop the platform for seismic risk evaluation and
53 integrate the inputs from the aforementioned
54 subgroups.

55 The collaborative research was initiated and
56 required researches were appointed in the first year of

57 the research project. As a preliminary study, the
58 methodology of the entire research was constructed by
59 the platform development group and models in related
60 research fields were selected by corresponding
61 research subgroups. Then, the process of seismic risk
62 evaluation was revised and extended on the basis of a
63 methodology determined in the preliminary study. The
64 ground motion prediction equations (GMPEs) and risk
65 models were revised and target sites were expanded to
66 the whole prefecture.

67 2.1.2. Specific Research

68 Specific research topics were selected on the basis
69 of discussions carried out in “Integrated Research.”
70 Table 1 shows the specific research conducted from
71 FY2015 to FY2018.

Table. 1 Topics of the specific research for each fiscal year.

Fiscal year	Research topics	
	Title	PI ^a
2015	Study on disaster risk assessment considering the time line	Shinichi Matsushima (DPRI, KU)
	Integrated simulation for economical assessment of seismic damage	Muneo Hori (ERI, UT)
2016	Study on disaster risk assessment considering the time line	Shinichi Matsushima (DPRI, KU)
	Integrated simulation for economical assessment of seismic damage	Muneo Hori (ERI, UT)
	Construction of source models for evaluation of disaster risk for large earthquakes	Takashi Furumura (ERI, UT)
	Improvement of structural damage estimation methods	Hiroshi Kawase (DPRI, KU)
2017	Construction of source models for evaluation of disaster risk for large earthquakes	Takashi Furumura (ERI, UT)
	Improvement of structural damage estimation methods	Hiroshi Kawase (DPRI, KU)
	Increasing precision of estimation methods of soil amplification during large earthquakes	Kyohei Ueda (DPRI, KU)
	Improvement of strong motion estimation following large earthquakes focused on the source model	Masatoshi Miyazawa (DPRI, KU)
2018	Increasing precision of estimation methods of soil amplification during large earthquakes	Kyohei Ueda (DPRI, KU)
	Improvement of strong motion estimation following large earthquakes focused on the source model	Masatoshi Miyazawa (DPRI, KU)
	Study on disaster prevention planning based on damage risk assessment with uncertainty	Norio Maki (DPRI, KU)
	Data analysis and construction of modelling method for estimating exposure in the future	Kazuyoshi Nishijima (DPRI, KU)

a. Principal investigator

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2.2. Subject Proposal Type Research

Earthquake and/or volcanic disasters are caused by the vulnerability of the human and social environment when hazards such as strong motions, tsunamis, volcanic ashes and/or lava flow from earthquakes and volcanic eruptions act on them. Disaster science concerning earthquakes and volcanic eruptions is geared toward to understanding the occurrence of events and the occurrence and transition of disasters caused by those events and in utilizing such knowledge to prevent/mitigate disaster. For this purpose, researchers in areas of physics, engineering, and cultural and social science are required to cooperate and conduct interdisciplinary and comprehensive research and pursue them to understand the cause of disasters.

“Subject Proposal Type Research” involved the following five categories: 1. study of cases of earthquake/volcanic disaster, 2. improvement of prior evaluation methods for earthquake/volcanic hazards, 3. improvement of real-time estimation methods for earthquake/volcanic hazards, 4. investigation of the mechanism of earthquake/volcanic disaster occurrence, and 5. improvement of information dissemination to mitigate earthquake/volcanic disasters.

Table 2 shows the number of research projects that were conducted for “Subject Proposal Type Research” from FY2014 to FY2018.

Table. 2 Number research projects of the Subject Proposal Type Research for each fiscal year.

Fiscal year	Research categories					Total
	1	2	3	4	5	
2014	3	3	3	1	2	12
2015	2	4	4	1	1	12
2016	2	1	3	1	5	12
2017	2	1	3	2	3	11
2018	2	2	1	1	1	7
Total	11	11	14	6	12	54

2.3. Reports of Research

A brief report of each research project conducted during the five years can be found at the web site maintained by the Coordinating Committee of Earthquake and Volcanic Eruption Prediction Researches [1].

3. Understanding Uncertainty of Seismic Risk Evaluation for Earthquakes along the Nankai Trough

In “Integrated Research” of “Participation Type Research,” research by the eight subgroups mentioned in Section 2.1 was conducted to understand the

uncertainty of seismic risk evaluation for earthquakes occurring along the Nankai Trough.

In this chapter, the output of “Integrated Research” of “Participation Type Research” is explained in detail, since this is the main feature of the Core-to-Core Research.

In the first year of the 5-year research project, a working group was formed to discuss the research objective, which was determined to be mitigation of disasters caused by large magnitude earthquakes along the Nankai Trough. A symposium was held at ERI, wherein researchers from related research areas gathered to discuss about the specific research plan for the Core-to-Core Research. In the symposium, it was agreed that seismic risk and its uncertainty would be evaluated using state-of-the-art methods.

In the initial phase of the research, a preliminary study for developing a methodology for evaluating seismic risk was conducted by the platform development subgroup. Models to be used for the related research fields were then selected by the corresponding subgroups. The target location was the prefectural offices of Kochi and Osaka prefectures. For the secondary study beginning in FY2016, the procedure of seismic risk evaluation was revised and extended on basis of the methodology developed in the preliminary study. The target location was expanded to the whole of Kochi and Osaka prefectures.

3.1. Preliminary Study

3.1.1. Scope of the study

The scope of the preliminary study was limited to evaluating the expected loss due to the damage of an arbitrary structure for the next Nankai Trough earthquake at arbitrary locations. The location of the assumed source region of an earthquake occurring along the Nankai Trough and the two target sites are shown in Fig. 1. The conditions of the research were set to evaluate seismic risk for direct economic loss due to damage of 2-storey wooden houses located at the prefectural offices of Osaka and Kochi prefectures.

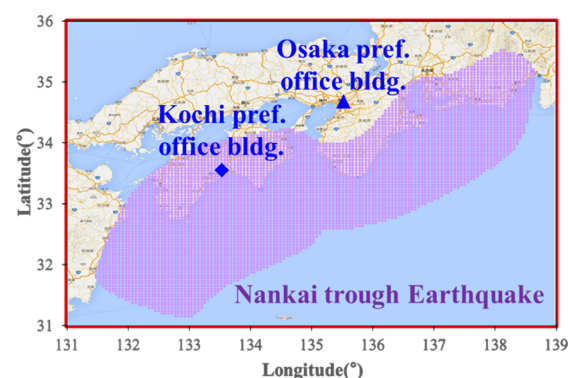
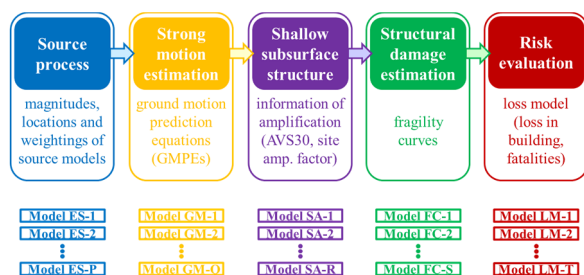


Fig. 1. Locations of the source area of the Nankai Trough earthquake and target sites.

3.1.2. Procedure of the study

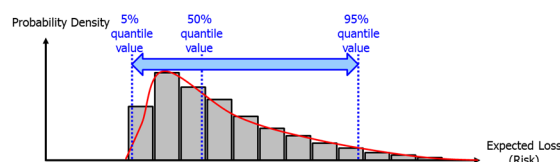
In this study, probabilistic seismic risk evaluation is composed of five modules, i.e. source process modelling, strong motion estimation, shallow subsurface structure amplification, structural damage estimation and risk evaluation, which are sequentially connected as illustrated in Fig. 2. The output from the upstream module is used as the input for the following module. The magnitude and location of several earthquake source areas are defined and combined to construct source models. The source area is decided according to the magnitude. In order to consider the possibility of occurrence of the next event, the source models are weighted according to the judgement of the source model subgroup. Peak ground velocity (PGV) of ground motions at the target sites was predicted in the strong motion estimation module. Effects of site amplifications were estimated in the shallow subsurface structure module, while the vulnerability of the target structure was estimated using fragility curves in the structural damage estimation module. In the risk evaluation module, seismic risk was evaluated in terms of the expected value of loss.



Source: 5th IASPEI / IAEE international Symposium: Effects of Surface Geology on Seismic Motion [2]

Fig. 2. Sequential process of modules for the evaluation of seismic risk and its uncertainty.

In this study, the misfits of the models to the data and/or the presence of competing models are considered as epistemic uncertainty; the overall uncertainty of the calculated seismic risk is influenced by each epistemic uncertainty. Each epistemic uncertainty is estimated by each research subgroup and the overall uncertainty is evaluated considering those epistemic uncertainties. A great number of combinations of models and modelling uncertainties are assumed to calculate risk on the basis of Monte-Carlo Simulation (MCS); the probabilistic distribution of risk is obtained from the results of the MCS. The overall uncertainty in the calculated risk is defined on the basis of the probabilistic distribution. The degree



Source: 5th IASPEI / IAEE international Symposium: Effects of Surface Geology on Seismic Motion [2]

Fig. 3. The definition of the degree of uncertainty.

of uncertainty is defined as the length of the interval between the 5% quantile value and the 95% quantile value of the expected losses obtained from the MCS results, as shown as a schematic figure in Fig. 3.

The ultimate goal of this research is to investigate possibilities to reduce the overall uncertainty of seismic risk. A sensitivity analysis with quantified values of risks and their uncertainties was performed to investigate which part's uncertainty has the largest effect on the overall uncertainty. First, the reference value of overall uncertainty is evaluated in case uncertainties of all parts exist. This uncertainty is called "original uncertainty" in this paper. Second, overall uncertainty is calculated when we do not consider uncertainty of the source model and uncertainties of all the other parts exist. The same process is performed with respect to GMPEs, site amplification, fragility curve and loss model parts. Third, the most important part is defined by comparing the variation in the overall uncertainty for each case. If the overall uncertainty is significantly affected by the uncertainty of a certain part, the uncertainty of that part should be considered as an important factor to reduce the overall uncertainty. An image of sensitivity analysis is illustrated in Fig. 4. In Fig. 4, the uncertainty of GMPE is most sensitive to the overall uncertainty.

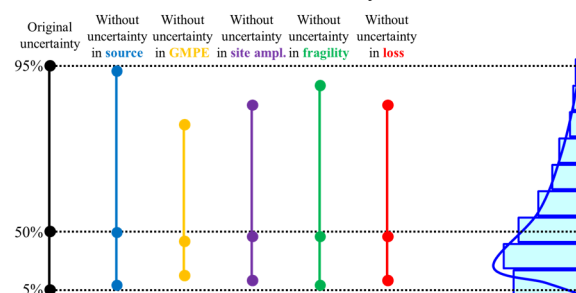


Fig. 4. Image of sensitivity analysis.

3.1.3. Models applied in the source process study

Source process

Six source areas were selected for the Nankai Trough earthquake based on the Japan Seismic Hazard Information System (J-SHIS) [3]. The moment magnitude (M_w) values of six source areas are assumed as 9.1, 8.7, 8.3, 8.5, 8.2, and 8.4. The shortest distance from six sources to the Kochi prefectural office site are 25.7, 25.6, 227, 25.6, 227, and 25.6 km, respectively. Those to the Osaka prefectural office site are 70.9, 107, 107, 114, 107, and 114 km, respectively. Six source models were proposed by combining six source areas as shown in Fig. 5. While the former two source models consist of a single source area, the other four source models consist of two source areas. When there are two source areas in a source model, it is considered that the two source areas will rupture at a certain time interval, but not concurrently. Weights of source models were assumed as 10, 30, 15, 15, 15, and 15%, for source models (SM) 1 to 6, respectively. The probability of occurrence of the earthquake is not considered, so the conditional risk is considered under the conditions of the occurrence of an earthquake.

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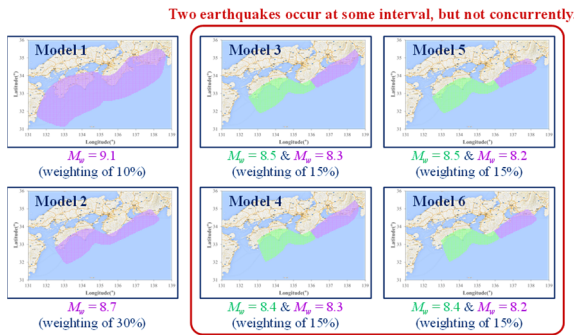


Fig. 5. Six source models for the Nankai Trough earthquake proposed in this study.

1 Strong motion estimation

2 GMPEs are empirical attenuation relation derived
3 from regression analysis. In this study, GMPEs that
4 have been developed based on Japanese data and are
5 capable of estimating PGVs are used for the seismic
6 risk evaluation. They are defined as follows;

$$7 \log PGV_{EB} = f(M_w, X, \Lambda) + \varepsilon_{GMPE} \dots \dots \dots (1)$$

8 where, PGV_{EB} is PGV at the engineering bedrock of
9 the target site. M_w is the moment magnitude of the
10 source area, and X is the shortest distance to the
11 source from the site. Each GMPE model has an error
12 term considering modelling uncertainty, ε_{GMPE} . The
13 value of ε_{GMPE} is randomly selected using normal
14 distribution with standard deviation (σ) values of
15 corresponding GMPEs. Since ε_{GMPE} is assumed as
16 being normally distributed, the predicted PGVs will be
17 lognormally distributed.

18 Five GMPE models were selected for strong motion
19 estimation module; Si and Midorikawa [4] (GMPE1),
20 Kanno and others [5] (GMPE2), Satoh [6] (GMPE3),
21 and Morikawa and Fujiwara [7] (GMPE4 and
22 GMPE5). In this study, only GMPE4 and GMPE5 are
23 applicable for SM1 whose moment magnitude is over
24 9, while all five GMPEs can be applied in the other
25 five source models whose M_w is under 9. The reason
26 is that the saturation effect for an earthquake with of a
27 large magnitude is considered only in GMPE4 and
28 GMPE5, but not in the other three GMPEs.

29 In this study, PGV at the engineering bedrock where
30 the average shear-wave velocity (V_s) for top 30 m
31 depth (AVS30) is 600 m/s, is first estimated. PGVs
32 predicted by GMPE2 to GMPE5 are targeted for
33 engineering bedrock with AVS30 of 311, 500, 350 and
34 350 m/s, respectively. The predicted PGVs for these
35 five GMPEs include the effect of site amplification:
36 thus the predicted PGVs needs to be adjusted to PGVs
37 at engineering bedrock with AVS30 of 600m/s. The
38 conversion procedure of PGVs predicted by five
39 GMPEs is illustrated in Fig. 6. In case of GMPE2,
40 PGV is converted by its own converting relation [5],
41 but the converting relation by Fujimoto and
42 Midorikawa [8], shown in Eq. (4), is applied for PGVs
43 by other GMPEs. The comparison of the predicted and

44 converted PGVs of five GMPEs are shown in Fig. 7,
45 in case of the source model 2 whose M_w is 8.7 and
46 focal depth is 19.2 km.

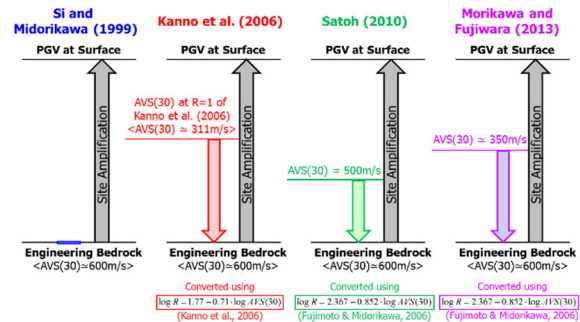


Fig. 6. Conversion of PGVs by five GMPEs.

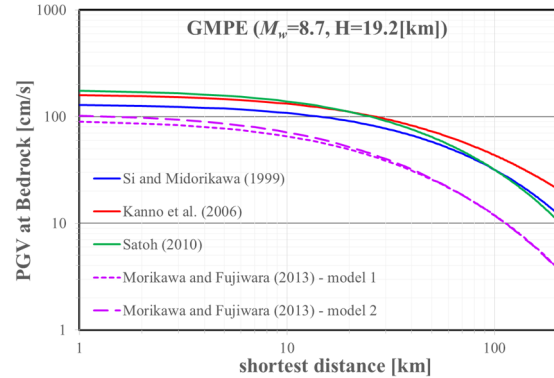


Fig. 7. Comparison of PGVs by five GMPEs.

47 Shallow subsurface structure

48 The site amplification from engineering bedrock
49 with AVS30 of 600m/s to the surface is defined by the
50 site amplification model. In this study, the site
51 amplification model was proposed for the shallow
52 subsurface structure module as a simplified format as
53 follows;

$$54 PGV_{GS} = AF \cdot PGV_{EB} \dots \dots \dots (2)$$

55 where, PGV_{GS} and AF are PGV at the ground
56 surface and the amplification factor of the site,
57 respectively.

58 In this study, the site amplification factor of PGV is
59 estimated through two steps. The first step is the
60 estimation of AVS30 from the soil profile based on the
61 study by Matsuoka and others [9] as shown in Eq. (3).
62 AVS30 is defined as the function of conditions of the
63 site for each geomorphologic classification, such as
64 elevation (Ev), slope (Sp), and distance from
65 mountain or hill (Dm). Information of
66 geomorphologic classification of J-SHIS [3] is applied.
67 ε_{SA1} is modelling uncertainty in the first step. The
68 second step is the estimation of amplification factor
69 from estimated AVS30 as shown in Eq. (4) [8]. ε_{SA2}
70 is modelling uncertainty in the second step. The
71 methods of applying modelling uncertainties are the
72 same as those in GMPEs. The standard deviation of
73 previous studies [9, 8] is applied as ε_{SA1} and ε_{SA2} .
74 Epsilons are also assumed to be normally distributed;

1 therefore, the predicted PGV at the ground surface will
2 likewise follow a log-normal distribution.

3 $\log AVS30 = f(Ev, Sp, Dm) + \varepsilon_{SA1} \dots\dots\dots(3)$

4 $\log AF = 2.367 - 0.852 \log AVS30 + \varepsilon_{SA2} \dots(4)$

5 *Structural damage estimation*

6 The fragility curve model for 2-storey wooden
7 houses defined by Murao and Yamazaki [10] was
8 selected for the structure damage estimation module.
9 The exceedance probability P_R , which is the
10 probability that damage of rank R or worse will occur
11 for a ground motion of PGV_{GS} , is defined using a
12 cumulative probability distribution function Φ . Φ is a
13 standard normal distribution and P_R is assumed to be
14 lognormally distributed as follows;

15 $P_R(PGV_{GS}) = \Phi\left(\frac{\ln PGV_{GS} - \ln \mu_D}{\zeta_D}\right) \dots\dots\dots(5)$

16 where, μ_D is the modelling uncertainty term assumed
17 in this study. $\ln \mu_D$ is assumed as lognormally
18 distributed with distribution parameters of λ and ζ_λ .
19 ζ_λ is the coefficient of variation (c.o.v.) of $\ln \mu_D$, and
20 is assumed as 20% in this study. λ and ζ_D are
21 parameters of the fragility curve, corresponding to the
22 mean and standard deviation of $\ln PGV_{GS}$,
23 respectively.

24 Damage degree for wooden houses is classified as
25 heavy, moderate, and partial damage. The same
26 fragility curve model is applied to the different damage
27 degrees, but the parameters, λ and ζ_D , are applied
28 separately. The parameters of fragility curves for 3
29 damage degrees are presented in Table 3, and the
30 fragility curves corresponding to 3 damage degrees are
31 shown in Fig. 8.

Table. 3 Parameters of the fragility curve for wooden house [10].

Structure	Damage	λ	ζ_D
Wooden house	partial	4.13	0.566
	moderate	4.67	0.478
	heavy	4.90	0.447

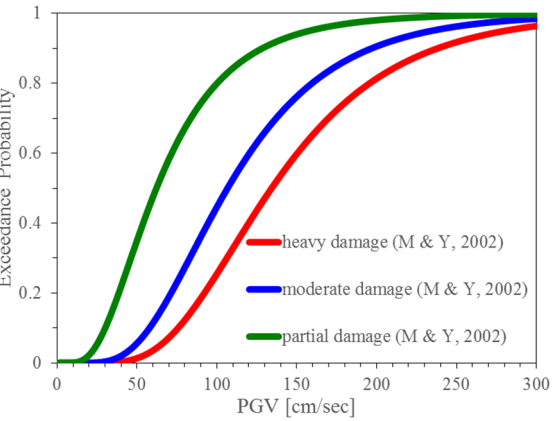


Fig. 8. Fragility curves for wooden houses [10].

32 *Risk evaluation*

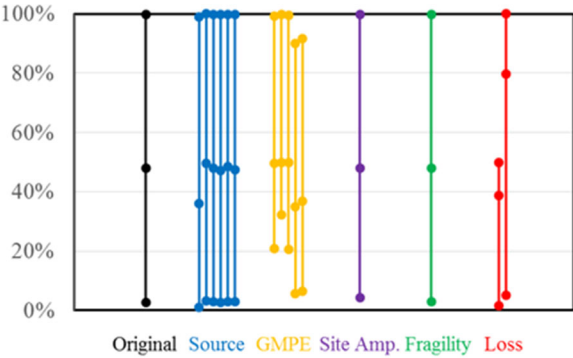
33 Risk is defined as the expected value of loss. A
34 simplified loss model is proposed for the risk
35 evaluation module. Quantified values for direct
36 (economic) losses [10] shown in Table 4, are applied
37 as a loss model. The lower bound of values of loss for
38 each damage degree are applied for loss model 1
39 (LM1) and the upper bound values are applied for loss
40 model 2 (LM2). In case of the partial damage in LM1,
41 5% loss is used for the lowest value.

Table. 4 Quantified values for direct (economic) loss [10].

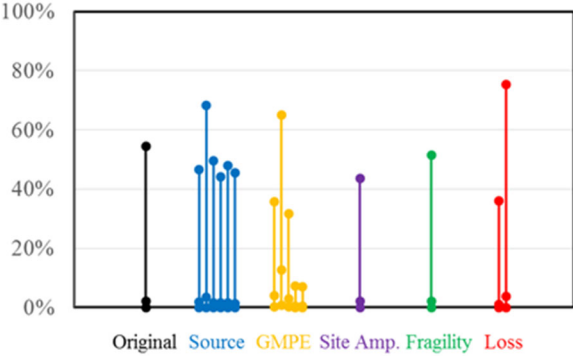
Structure	Damage	Loss
Wooden house	partial	0% ~ 20% of loss
	moderate	20% ~ 50% of loss
	heavy	50% ~ 100% of loss

42 3.1.4. Result of the sensitivity analysis

43 Sensitivity analyses are performed for two target
44 sites. The results are shown in Fig. 9. Quantile values
45 of 5, 50 and 95% are shown by the dot for loss estimate
46 line for each case. Very large uncertainties in the
47 calculated risks are observed in all cases, especially in
48 case of Kochi prefectural office site. For the
49 comparison of uncertainty, the rate of reduction in
50 uncertainty with respect to original uncertainty is
51 defined as a criterion. The reduction rates are
52 presented in Table 5. Based on the reduction rate of
53 each case, uncertainty of GMPEs are most influential
54 to overall uncertainty. Those of site amplification and
55 loss model were less sensitive, where those of source
56 process and fragility curve were relatively insensitive.



(a) Kochi prefecture office site



(b) Osaka prefecture office site

Fig. 9. Results of sensitivity analysis.

Table. 5 Rate of reduction of uncertainty.

Module	Kochi pref. office	Osaka pref. office
Source process	0%	2%
GMPEs	19%	46%
Site amplification	2%	20%
Fragility curve	1%	5%
Loss	26%	-2%

3.1.5. Issues of preliminary analysis and challenges for the next step

From the preliminary study, some research agendas were found necessary to be investigated. First, the validity of suggested GMPEs needed to be verified because great differences were observed not only in the expected losses but also in the predicted PGVs as shown in Fig. 7. Second, the loss model needs to be defined more sophisticatedly since it was too simple and distinctive, and had more assumptions compared with other models.

3.2. Seismic risk evaluation

The secondary study was performed to conduct actual seismic risk evaluation for the whole area of the Kochi and Osaka prefectures, along with research to solve the aforementioned research agendas.

3.2.1. Revision of GMPEs

According to a recent paper [11], the effect of saturation of ground motions needs to be considered for megathrust earthquakes at the subduction zone. Based on the study, in case the shortest distance from source to site is applied for GMPEs, saturation of M_w needs to be considered for M_w over 8.3. This idea is adapted for GMPE1 to GMPE3, since the saturation effect is considered in GMPE4 and GMPE5 [7]. Except for two source areas whose M_w are 8.3 and 8.2, M_w is larger than 8.3, and therefore the saturation effect is considered for every source model. The comparison of the predicted PGVs of revised five GMPEs is illustrated in Fig. 10.

Compared with Fig. 7, the variability in the predicted PGVs decreased. The results of sensitivity analyses including the effect of saturation of

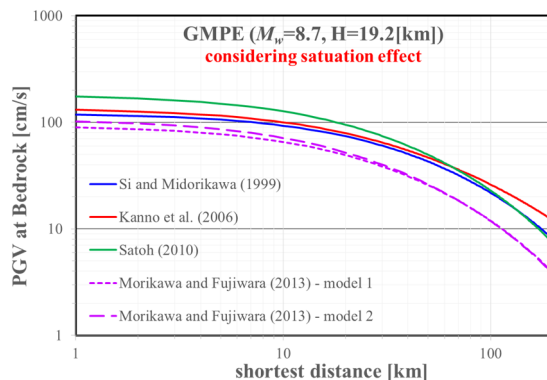
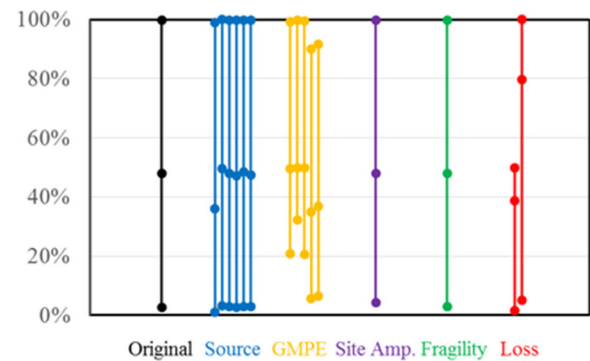


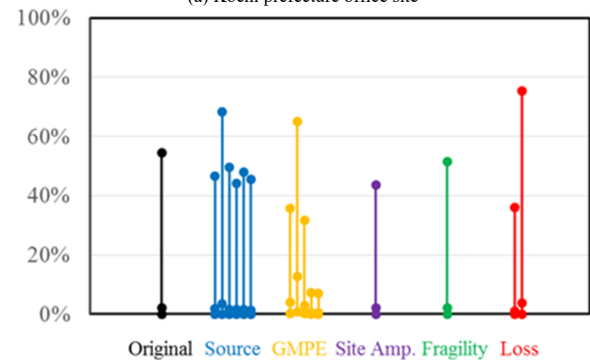
Fig. 10. Comparison of PGVs by 5 GMPEs considering saturation.

magnitude for GMPEs are shown in Fig. 11. The decrease in expected risk values lead to a decrease of their uncertainties. Based on the reduction rate of each case, the relative relation of influence to the results does not change

As shown in Fig. 9(a), the expected loss at the Kochi prefectural office site by SM1 is smaller than others despite its M_w being much larger than the others. This was improved as shown in Fig. 11(a), mainly because not only GMPE4 and GMPE5 but also GMPE1 to GMPE3, which predicts larger PGVs, were applied to SM1.



(a) Kochi prefecture office site



(b) Osaka prefecture office site

Fig. 11. Sensitivity analysis results for direct loss of houses considering the revision in GMPEs.

3.2.2. Revision of loss model

The risk is defined as the expected values of the rates of losses in terms of the fatalities as well as the direct losses of wooden houses. The death rate (casualties per house) defined by Tabata and Okada [12] is applied to link the damage of wooden houses to the fatalities, from the relation between the damage index and the rate collapse of surrounding houses as follows;

$$D_r(x, y) = ae^{bx} + cxy^2 \dots\dots\dots(6)$$

where, $D_r(x, y)$ is the rate of casualties per wooden house. x is the damage index of the wooden house, and y is the surrounding collapse rate. Parameters of a , b , and c are obtained by regression as 0.0104, 6.68, and 11.0, respectively, for a single wooden house.

Since data for the surrounding collapse rate is not always easily accessible, it is assumed as the function of damage index, which is estimated from the data of

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1 Kobe city [12], as shown in Fig. 12. The estimated
2 function is $y = x^2/2$, and the death rate per wooden
3 house is defined by the function of damage index as
4 Eq. (7) marked by red line in Fig. 12.

$$5 \quad D_r(x, y) = ae^{bx} + cx(x^2/2)^2 \dots \dots \dots (7)$$

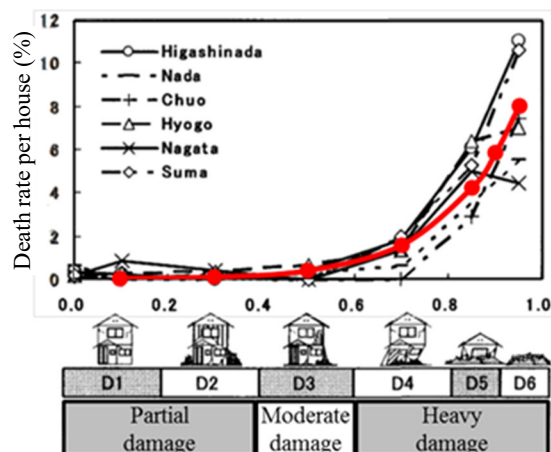


Fig. 12. Data of Kobe city and the approximated seismic death rate function for casualties per wooden house (after [12]).

6 Damage indices need to be quantified to be applied
7 to the death rate function for casualties per wooden
8 house. Quantified damage indices applied in the study
9 [12] are marked by dotted lines in Fig. 13. These
10 values are based on the fragility curves defined in
11 Okada and Takai [13] as marked by dotted and dashed
12 lines in Fig. 14. Since the fragility curves by Murao
13 and Yamazaki [10], marked by solid lines in Fig. 14,
14 are applied in this study instead of those by Okada
15 Takai [13], the damage indices for the death rate
16 function needs to be revised. From the comparison of
17 fragility curves of Murao and Yamazaki [10] and
18 Okada and Takai [13], the damage indices for death
19 rate function are revised to those marked by solid lines
20 in Fig. 13.

21 The quantified values for the rate of direct loss of
22 houses are improved based on the strict meaning of the

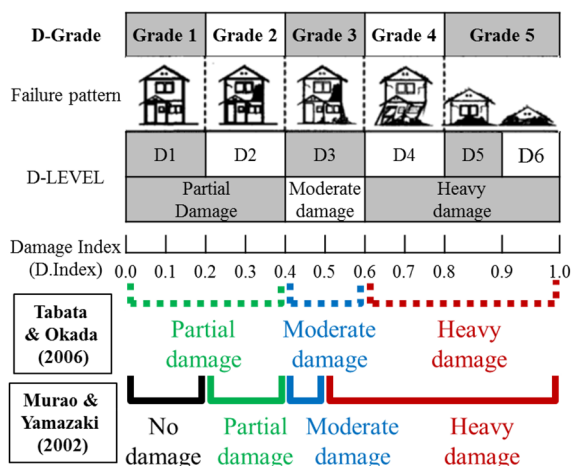


Fig. 13. Data of Kobe city and the approximated seismic death rate function for casualties per wooden house (after [12]).

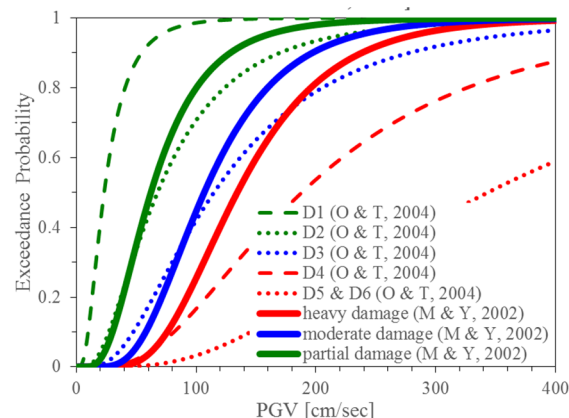


Fig. 14. Comparison of fragility curves [10, 13].

23 rate of loss [10]. As shown in Fig. 15, the degree of
24 loss rate depends on the judgement of investigator. In
25 the preliminary study, the values for the rate of direct
26 loss based on the survey conducted by the local
27 government were directly applied in the loss model.
28 However, since the fragility curves applied in this
29 study are not based on the survey by the local
30 government, but rather on that by the "Special
31 Committee for Earthquake Disaster Recovery and
32 Urban Reconstruction," the quantified values need to
33 be changed. The quantified values are revised as
34 shown in Fig. 16 based on the comparisons of

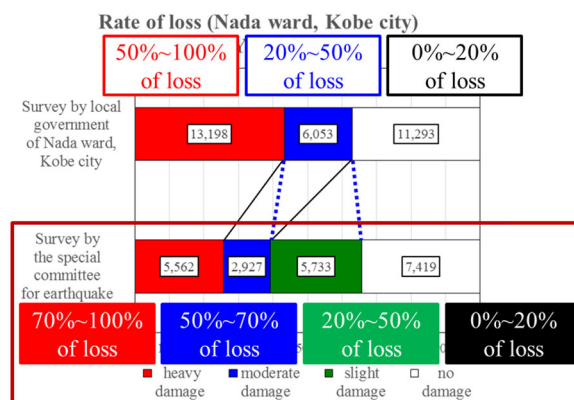


Fig. 15. Differences in quantified values of rates of losses in building affected by the judgements of investigators [10].

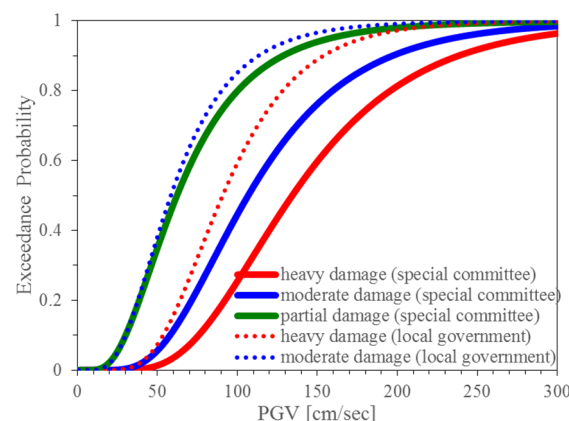


Fig. 16. Comparison of fragility curves affected by the judgements of investigators [10].

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1 proportions for damage degrees and fragility curves as
2 illustrated in Fig. 15 and Fig. 16, respectively.
3 One more improvement to the loss model is carried
4 out by adding a model with a median value and
5 considering uncertainty in the loss model by assuming
6 a uniform distribution instead of random selection of
7 values in each category.
8 The final loss model revised is briefly illustrated in
9 Fig. 17. First, the classification of damage is revised
10 from three classes to four classes. Second, the
11 quantified damage indexes are defined. Finally, the
12 loss model is defined in terms of rates of fatalities and
13 direct loss of houses with respect to damage indices.
14 The results of sensitivity analyses including the
15 revision in the loss model are presented in Fig. 18.
16 Expected values of risks are decreased because of the
17 revisions in quantified values for the rate of loss of
18 houses. Uncertainties are decreased at the Kochi
19 prefectural office site but increased at the Osaka
20 prefectural office site.

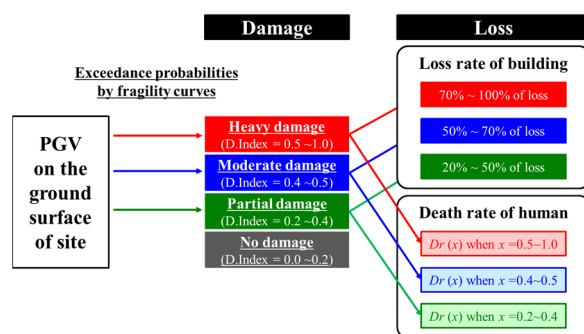


Fig. 17. Illustration of the loss model.

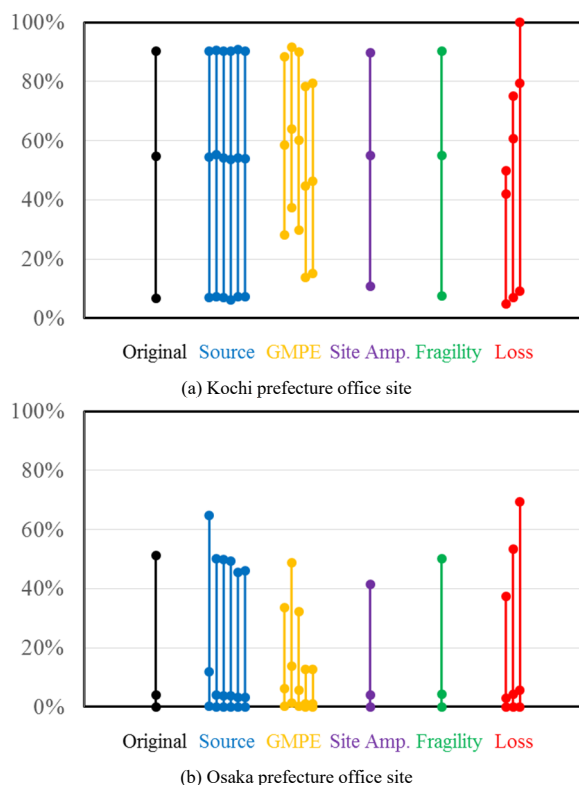


Fig. 18. Sensitivity analysis results of direct losses of houses considering the revision in loss model.

3.2.3. Expansion of target sites

21 The evaluation of seismic risk and its uncertainty
22 has been extended to entire the Kochi and Osaka
23 prefectures using revised methodology. The number of
24 meshes of Kochi and Osaka prefectures are 103,465
25 and 27,640, and the size of a mesh is 100m×100m.

26 The expected rates of building losses for a wooden
27 house and those of the corresponding human losses are
28 illustrated in Fig. 19(a) and Fig. 19(b), respectively.
29 The expected values were very high, around 50% of
30 losses in buildings and around 3% of fatalities are
31 predicted, in certain places of Kochi prefecture, which
32 is around Kochi city. Compared with Kochi prefecture,
33 those of Osaka prefecture are relatively small.

34 The uncertainties of rates of building losses for a
35 wooden house and those of human losses are
36 illustrated in Fig. 20(a) and Fig. 20(b), respectively.
37 Overall uncertainties are large in the Kochi prefecture
38 and those of the Osaka prefecture are relatively small.
39 The spatial distribution of the uncertainty reduction
40 rates in building losses in Kochi and Osaka prefectures
41 is illustrated in Fig. 21. Based on the results of a
42 sensitivity analysis, the conclusion is slightly different.
43 The effect of the loss model is less important than
44 previous results of sensitivity analysis. The spatial
45 distribution of the uncertainty reduction rates of the
46 human losses in Kochi and Osaka prefectures is
47 illustrated in Fig. 22. Based on the results of a
48 sensitivity analysis, the conclusion is the same as that
49 for the building losses. After the extension of sites, the
50 conclusion is almost similar but slightly changed.
51 Uncertainty in GMPEs is still most influential to
52 overall uncertainty, while that in site amplification is
53 less sensitive, and those of source process, fragility
54 curve and loss model are relatively insensitive.

3.3. Summary of risk evaluation for the Nankai Trough earthquake

56 “Integrated Research” was aimed at evaluating
57 seismic risk and its uncertainty for an earthquake
58 occurring along the Nankai Trough, by utilizing state-
59 of-the-art methods. In the preliminary study, very
60 large uncertainties in the calculated risks were
61 observed, especially for the Kochi prefectural office
62 site. For comparison of uncertainty, the rate of
63 reduction in uncertainty with respect to the original
64 uncertainty is defined as a criterion. Based on the
65 reduction rate of each case, the uncertainty of strong
66 motion simulation module is most influential to
67 overall uncertainty. Those of site amplification and
68 loss model modules were less sensitive, and those of
69 source process and structure damage estimation
70 modules were relatively insensitive.

71 After the preliminary study, the methodology for
72 seismic risk evaluation was improved in three parts.
73 First, the models for GMPEs were improved
74 considering the saturation effect. Second, the loss
75 model was improved by adding a human loss model
76 that is related to the direct loss of houses. The
77
78

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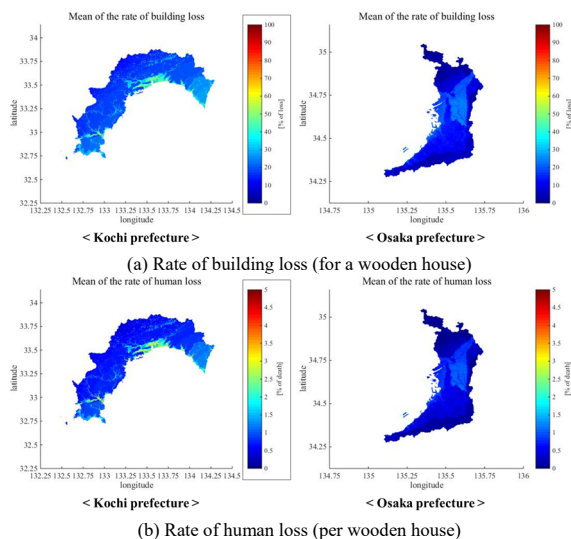


Fig. 19. Expected values of the seismic risk.

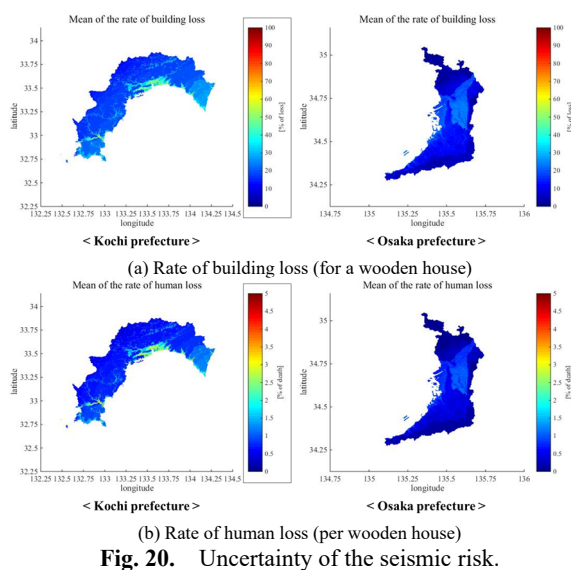


Fig. 20. Uncertainty of the seismic risk.

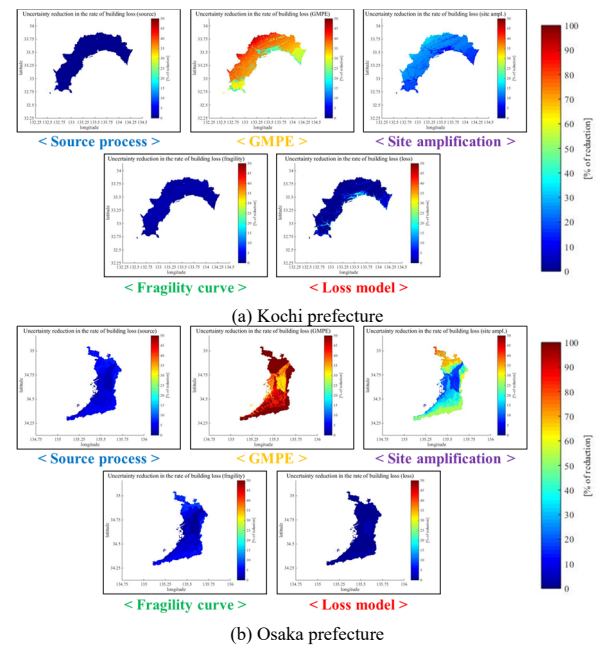


Fig. 21. Results of sensitivity analysis - Uncertainty reduction rate of loss of houses.

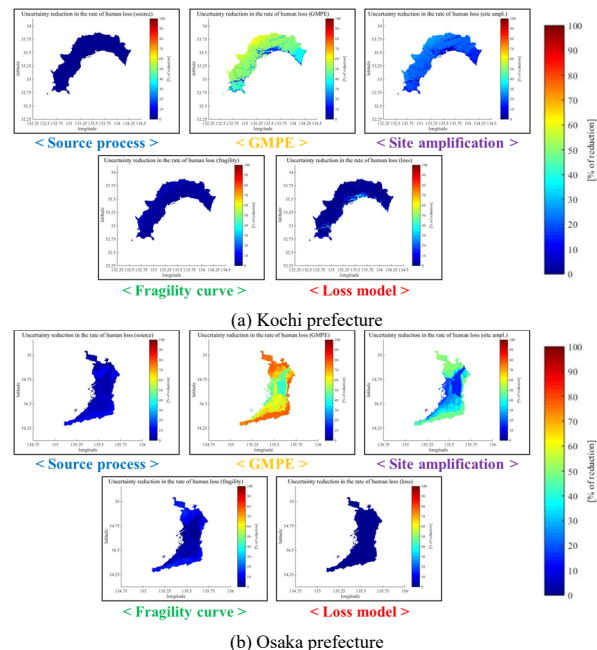


Fig. 22. Results of sensitivity analysis - Uncertainty reduction rate of human loss.

1 classification of damage degree and the quantified
2 value for the corresponding damage degree were
3 revised, and the application method of the loss model
4 was also revised. Third, target sites were extended to
5 the whole of Kochi and Osaka prefectures. The
6 conclusion did not change drastically after these three
7 parts were improved.
8 The expected rates of direct loss for a wooden house
9 and the corresponding human loss were found to be
10 very high, around 50% of losses in houses and around
11 3% of fatalities per house were predicted, in certain
12 places in the Kochi prefecture. Compared with the
13 Kochi prefecture, those of the Osaka prefecture were
14 relatively small. The uncertainties of loss of wooden
15 houses and human loss were also found to be large in
16 the Kochi prefecture and those of the Osaka prefecture
17 were relatively small. Uncertainty in strong motion
18 estimation module is still most influential to the
19 overall uncertainty, while that in site amplification
20 module is less sensitive, and those of source process,
21 fragility curve and loss model modules are relatively
22 insensitive.

23 4. Summary of the Core-to-Core Research

24 The Core-to-Core Collaborative Research between
25 Earthquake Research Institute, University of Tokyo
26 (ERI) and Disaster Prevention Research Institute,
27 Kyoto University (DPRI) started in FY2014 as a new
28 format of a collaborative research within the research
29 project Earthquake and Volcano Hazards Observation
30 and Research Program. During the period between
31 FY2014 and FY2018, Participation Type Research
32 and Subject Proposal Type Research were conducted.
33 In "Subject Proposal Type Research", a total of 54
34 research proposals were accepted for researchers in
35 areas such as physics, engineering, and cultural and

Core-to-Core Collaborative Research between Earthquake Research Institute, University of Tokyo and Disaster Prevention Research Institute, Kyoto University during FY2014 and FY2018

social science to cooperate and conduct interdisciplinary and comprehensive research and pursue research to understand the cause of disasters and utilize the knowledge to prevent/mitigate disaster. In “Participation Type Research”, “Integrated Research” and “Specific Research” was conducted for “Construction of a New Paradigm for Improving Uncertainty of Risk Evaluation for Large Magnitude Earthquakes.” In “Integrated Research”, probabilistic seismic risk assessment at Osaka and Kochi prefectures associated with the occurrence of an earthquake along the Nankai Trough was conducted by combining research areas from source process to stakeholder involvement. As a result, the uncertainty of probabilistic seismic risk was explicitly expressed quantitatively.

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***Profiles and photos are not necessarily required at the first submission.**



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